EO/US
PCT/US00/31429

PATENT COOPERATION TREATY

10/069,556

PCT

From the INTERNATIONAL BUREAU

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

JUL 08 2002

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

Date of mailing: 23 May 2002 (23.05.02)	
International application No.: PCT/US00/31429	Applicant's or agent's file reference:
International filing date: 15 November 2000 (15.11.00)	Priority date:
Applicant: GORNALL, William, S. et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International preliminary Examining Authority on:

08 March 2001 (08.03.01)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740 14 35

Authorized officer:

J. Zahra

Telephone No.: (41-22) 338 83 38

TENT COOPERATION TRE

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To: MARTIN LUKACHER C/O WILLIAM S. GORNALL BURLEIGH INSTRUMENTS, INC. 7647 MAIN STREET FISHERS, NY 14453	**PCT** NOTIFICATION OF TRANSMITTAL OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT **(PCT Rule 71.1)**
	Date of Mailing *(day/month/year)* 07 FEB 2002
Applicant's or agent's file reference B - 5	**IMPORTANT NOTIFICATION**

International application No.	International filing date *(day/month/year)*	Priority Date *(day/month/year)*
PCT/US00/31429	15 NOVEMBER 2000	NONE

Applicant
Burleigh Instruments, Inc.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices)(Article 39(1))(see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	FRANK G. FONT
Facsimile No. (703) 305-3230	Telephone No. (703) 308-0956

Deborah Parry-Leeper
Paralegal Specialist
Technology Center 2800

●ATENT COOPERATION TR Y

From the INTERNATIONAL SEARCHING AUTHORITY

To: MARTIN LUKACHER
C/O WILLIAM S. GORNALL
BURLEIGH INSTRUMENTS, INC.
7647 MAIN STREET
FISHERS, NY 14453

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

	Date of Mailing *(day/month/year)* 17 JAN 2001
Applicant's or agent's file reference B - 5	**FOR FURTHER ACTION** **See paragraphs 1 and 4 below**
International application No. PCT/US00/31429	International filing date *(day/month/year)* 15 NOVEMBER 2000
Applicant Burleigh Instruments, Inc.	

1. [X] The applicant is hereby notified that the international search report has been established and is transmitted herewith.

Filing of amendments and statement under Article 19:
The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the international search report; however, for more details, see the notes on the accompanying sheet.

Where? Directly to the International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Facsimile No.: (41-22) 740.14.35

For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

[ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

[ ] no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in rules 90 *bis* 1 and 90 *bis* 3, respectively, before the completion of the technical preparations for international publication.

Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer PHILIP NATIVIDAD Telephone No. (703) 308-0956

 (See notes on accompanying sheet)

ATENT COOPERATION TRE

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference B - 5	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
International application No. PCT/US00/31429	International filing date *(day/month/year)* 15 NOVEMBER 2000	(Earliest) Priority Date *(day/month/year)* NONE
Applicant Burleigh Instruments, Inc.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing:

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readable form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (See Box II).

4. With regard to the **title**,

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   [ ] the text is approved as submitted by the applicant.

   [X] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

   [ ] as suggested by the applicant.

   [X] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

The technical features mentioned in the abstract do not include a reference sign between parentheses (PCT Rule 8.1(d)).

NEW ABSTRACT

A long life laser wavelength meter is based on a Michelson interferometer with a flexure scanner. The scanner has a bar (18), preferably balanced about a pivot axis defined by a flexural pivot (16) which supports the bar (18). Retroreflectors (20) (22) are mounted on the bar (18), equally spaced from the pivot axis (16). Long life is obtained by cycling or oscillating the bar (18) over a limited range of angular movement within the bending limits of the flexure, which obtains a predicted, essentially infinite cycle life of the flexure. A large optical path length change for each scan of the oscillating bar (18) is obtained through the use of the retroreflectors (20) (22) which fold the optical paths of each arm of the interferometer (12) (14) before reaching a fixed end mirror (28). The end mirror (28) directs each optical path back through the same set of optical components, including the retroreflectors (20) (22), to a beamsplitter (38) which combines the light beams from both paths (12) (14) creating an optical interference beam output (46) to a detector (44). Wavelength measurements are based upon the use of a reference light beam of accurately known wavelength and an input beam of unknown wavelength that is to be measured. The reference beam and input beam traverse identical optical paths in the interferometer, to a measurement system which separately detects intensity fringes created by interference of the reference and input beams. By providing input and reference beams which are coincident and which traverse identical paths, systemic errors during scanning are substantially eliminated. Changes >100mm in optical path length are obtainable in a compact interferometer.

INTERNATIO SEARCH REPORT

International application No.
PCT/US00/31429

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G01J 3/45
US CL :356/455, 346
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 356/455, 346

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,124,929 A (WEIBEL) 26 September 2000 (26.09.2000), entire document.	1-26

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 DECEMBER 2000	17 JAN 2001

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer PHILIP NATIVIDAD Telephone No. (703) 308-0956

Form PCT/ISA/210 (second sheet) (July 1998)★

TENT COOPERATION TRE

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To: MARTIN LUKACHER
C/O WILLIAM S. GORNALL
BURLEIGH INSTRUMENTS, INC.
7647 MAIN STREET
FISHERS, NY 14453

PCT

WRITTEN OPINION

(PCT Rule 66)

Date of Mailing *(day/month/year)*	09 AUG 2001
REPLY DUE	within **TWO** months from the above date of mailing

Applicant's or agent's file reference		
B - 5		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US00/31429	15 NOVEMBER 2000	NONE

International Patent Classification (IPC) or both national classification and IPC
IPC(7): G01J 3/45 and US Cl.: 356/455, 346

Applicant
Burleigh Instruments, Inc.

1. This written opinion is the first (first, etc.) drawn by this International Preliminary Examining Authority.

2. This opinion contains indications relating to the following items:

- I [X] Basis of the opinion
- II [ ] Priority
- III [ ] Non-establishment of opinion with regard to novelty, inventive step or industrial applicability
- IV [ ] Lack of unity of invention
- V [X] Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI [ ] Certain documents cited
- VII [ ] Certain defects in the international application
- VIII [ ] Certain observations on the international application

3. The applicant is hereby invited to reply to this opinion.

When? See the time limit indicated above. ~~The applicant may, before the expiration of that time limit, request this Authority to grant an extension., see Rule 66.2(d).~~

How? By submitting a written reply, accompanied, where appropriate, by amendments, according to Rule 66.3. For the form and the language of the amendments, see Rules 66.8 and 66.9.

Also For an additional opportunity to submit amendments, see Rule 66.4.
For the examiner's obligation to consider amendments and/or arguments, see Rule 66.4 *bis*.
For an informal communication with the examiner, see Rule 66.6.

If no reply is filed, the international preliminary examination report will be established on the basis of this opinion.

4. The final date by which the international preliminary examination report must be established according to Rule 69.2 is: 15 MARCH 2003.

Name and mailing address of the IPEA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	FRANK G. FONT
Facsimile No. (703) 305-3230	Telephone No. (703) 308-0956

Form PCT/IPEA/408 (cover sheet) (July 1998)★

WRITTEN OPINION

International application No.

PCT/US00/31429

I. Basis of the opinion

1. With regard to the **elements** of the international application:*

[X] the international application as originally filed

[X] the description:

pages 1-11, as originally filed
pages NONE, filed with the demand
pages NONE, filed with the letter of

[X] the claims:

pages 12-15, as originally filed
pages NONE, as amended (together with any statement) under Article 19
pages NONE, filed with the demand
pages NONE, filed with the letter of

[X] the drawings:

pages 1-9, as originally filed
pages NONE, filed with the demand
pages NONE, filed with the letter of

[X] the sequence listing part of the description:

pages NONE, as originally filed
pages NONE, filed with the demand
pages NONE, filed with the letter of

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language ______ which is:

[ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

[ ] the language of publication of the international application (under Rule 48.3(b)).

[ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/ or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the written opinion was drawn on the basis of the sequence listing:

[ ] contained in the international application in printed form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readable form.

[ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] The statement that the information recorded in computer readable form is identical to the writen sequence listing has been furnished.

4. [X] The amendments have resulted in the cancellation of:

[X] the description, pages NONE
[X] the claims, Nos. NONE
[X] the drawings, sheets/~~fig~~ NONE

5. [ ] This opinion has been drawn as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this opinion as "originally filed".*

WRITTEN OPINION

International application No.
PCT/US00/31429

V. Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. statement

Novelty (N)	Claims	1-24	YES
	Claims	25-26	NO
Inventive Step (IS)	Claims	1-24	YES
	Claims	25-26	NO
Industrial Applicability (IA)	Claims	1-26	YES
	Claims	NONE	NO

2. citations and explanations

Claims 1-24 meet the criteria set out in PCT Article 33(2)-(4), because the prior art does not teach or fairly suggest an oscillating bar with flexural pivot over an arc within the bending limit of said pivot. Claims 1-26 have industrial applicability as in PCT Article 33(4), e.g., in wavelength meters for lasers or spectrometers.

Claims 25-26 lack novelty under PCT Article 33(2) as being anticipated by Weibel (US 6,124,929). See esp. Fig. 2.

------------------- NEW CITATIONS -------------------
NONE

WRITTEN OPINION

International application No.
PCT/US00/31429

Supplemental Box
(To be used when the space in any of the preceding boxes is not sufficient)

Continuation of: Boxes I - VIII

Sheet 10

TIME LIMIT:

The time limit set for response to a Written Opinion may not be extended. 37 CFR 1.484(d). Any response received after the expiration of the time limit set in the Written Opinion will not be considered in preparing the International Preliminary Examination Report.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference B - 5	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/US00/31429	International filing date *(day/month/year)* 15 NOVEMBER 2000	Priority date *(day/month/year)* NONE
International Patent Classification (IPC) or national classification and IPC IPC(7): G01J 3/45 and US Cl.: 356/455, 346		
Applicant Burleigh Instruments, Inc.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 3 sheets.

☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority. (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 0 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of report with regard to novelty, inventive step or industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☐ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 08 MARCH 2001	Date of completion of this report 11 JANUARY 2002
Name and mailing address of the IPEA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer FRANK G. FONT Deborah Perry-Leeper Paralegal Specialist Technology Center 2800 Telephone No. (703) 308-0956

Form PCT/IPEA/409 (cover sheet) (July 1998)★

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/US00/31429

I. Basis of the report

1. With regard to the **elements** of the international application:*

[X] the international application as originally filed

[X] the description:
pages 1-11 , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of ____

[X] the claims:
pages 12-15 , as originally filed
pages NONE , as amended (together with any statement) under Article 19
pages NONE , filed with the demand
pages NONE , filed with the letter of ____

[X] the drawings:
pages 1-9 , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of ____

[X] the sequence listing part of the description:
pages NONE , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of ____

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language ____ which is:

[ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

[ ] the language of publication of the international application (under Rule 48.3(b)).

[ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

[ ] contained in the international application in printed form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readable form.

[ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] The statement that the information recorded in computer readable form is identical to the writen sequence listing has been furnished.

4. [X] The amendments have resulted in the cancellation of:

[X] the description, pages NONE

[X] the claims, Nos. NONE

[X] the drawings, sheets/~~fig~~ NONE

5. [ ] This report has been drawn as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

** Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

***Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.*

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/US00/31429

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. statement

Novelty (N)	Claims	1-24	YES
	Claims	25-26	NO
Inventive Step (IS)	Claims	1-24	YES
	Claims	25-26	NO
Industrial Applicability (IA)	Claims	1-26	YES
	Claims	NONE	NO

2. citations and explanations (Rule 70.7)

Claims 1-24 meet the criteria set out in PCT Article 33(2)-(4), because the prior art does not teach or fairly suggest an oscillating bar with flexural pivot over an arc within the bending limit of said pivot. Claims 1-26 have industrial applicability as in PCT Article 33(4), e.g., in wavelength meters for lasers or spectrometers.

Claims 25-26 lack novelty under PCT Article 33(2) as being anticipated by Weibel (US 6,124,929). See esp. Fig. 2. Inherent in Fourier spectroscopy is that the unknown and reference wavelengths are together in the same light beam, which Weibel (and all Fourier-transform spectroscopic interferometers) divides with a beamsplitter such that all wavelengths travel to/from both the reference pathlength and the varying pathlength.

------------------- NEW CITATIONS -------------------
NONE

10/069556 2Fe1 2877

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 May 2002 (23.05.2002)

PCT

(10) International Publication Number
WO 02/40952 A1

(51) International Patent Classification[7]: G01J 3/45

(21) International Application Number: PCT/US00/31429

(22) International Filing Date: 15 November 2000 (15.11.2000)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (for all designated States except US): BURLEIGH INSTRUMENTS, INC. [US/US]; 7647 Main Street, P.O. Box E, Fishers, NY 14453 (US).

(72) Inventors; and
(75) Inventors/Applicants (for US only): GORNALL, William, S. [US/US]; 2 Saddle Ridge Trail, Fairport, NY 14450 (US). HOUK, Michael, T. [US/US]; 77 Squirrels Heath, Fairport, NY 14450 (US).

(74) Agent: LUKACHER, Martin; c/o Gornall, William, S., Burleigh Instruments, Inc., 7647 Main Street, Fishers, NY 14453 (US).

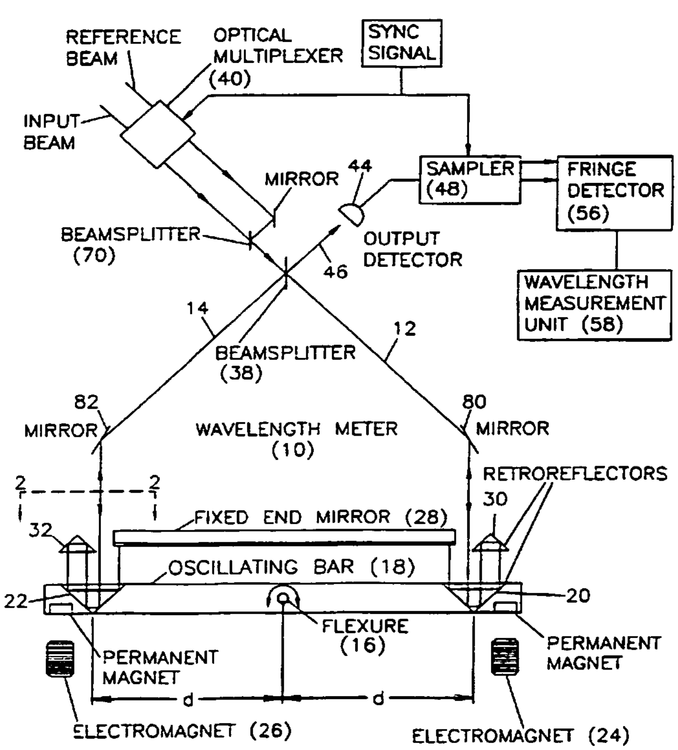
(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

[Continued on next page]

(54) Title: LASER WAVELENGTH METER



(57) Abstract: A long life laser wavelength meter is based on a Michelson interferometer with a flexure scanner. The scanner has a bar (18), preferably balanced about a pivot axis defined by a flexural pivot (16) which supports the bar (18). Retroreflectors (20, 22) are mounted on the bar (18), equally spaced from the pivot axis (16). Long life is obtained by cycling or oscillating the bar (18) over a limited range of angular movement within the binding limits of the flexure, which obtains a predicted, essentially infinite cycle life of the flexure. A large optical path length change for each scan of the oscillating bar (18) is obtained through the use of the retroreflectors (20, 22) which fold the optical paths of each arm of the interferometer (12, 14) before reaching a fixed end mirror (28). The end mirror (28) directs each optical path back through the same set of optical components, including the retroreflectors (20, 22), to a beamsplitter (38) which combines the light beams from both paths (12, 14) creating an optical interference beam output (46) to a detector (44). Wavelength measurements are based upon the use of a reference light beam of accurately known wavelength and an input light beam of unknown wavelength that is to be measured. The reference beam and input beam transverse identical optical paths in the interferometer, to a measurement system which separately detects intensity fringes created by interference of the reference and input beams. By providing input and reference beams which are coincident and which traverse identical paths systemic errors during scanning are substantially eliminated. Changes > 100mm in optical path length are obtainable in a compact interferometer.

WO 02/40952 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LASER WAVELENGTH METER

DESCRIPTION

The present invention relates to laser wavelength meters which measure the wavelength of an input beam of unknown wavelength with respect to a reference beam of known wavelength. More particularly, the invention provides a long life laser wavelength meter based on a Michelson interferometer with a flexure scanner. A wavelength meter provided by the invention features a large optical path length change through the use of a flexure which cycles over short distances within the specified bending range of the flexure. Such short cycle distances lead to long and practically infinite cycling life without damage to the flexure. The interferometer does not rely on rolling or rotary bearings, but rather on flexures operable over short cycle distances for long life, even in continuous operation.

Short cycle distances requisite for long flexure life are inconsistent with large optical path length change which is necessary for high accuracy wavelength meters. A large number of interference fringes (large change in the order number of the interferometer) for the input beam and the reference beam is necessary to make highly accurate wavelength measurements. Reference may be had to an article entitled "Laser Wavelength Meters" by J.J. Snyder which appeared in "Laser Focus" magazine for May 1982, pages 55 to 61, for information as to the relationship between optical path length change and the accuracy of the wavelength measurement.

In order to obtain requisite optical path length changes in an interferometer wavelength meter, linear scanners such as in the double arm linear bearing interferometer having movable retroreflectors shown in Gornall, U.S. Patent 4,319,843, issued March 16, 1982, may be used. Rotating mirror scanners such as a double arm rotary bearing interferometer described in Cutler, U.S. Patent 5,583,638, issued December 10, 1996 have also been suggested. Interferometers utilizing flexures have not achieved the long optical path length change needed for accuracy in

wavelength measurements, let alone long life. Reference may be had to Normarski, et al, U.S. Patent 3,825,348, issued July 23, 1974 in which flexure mounted mirrors are used, but which are limited in path length change to the short distance over which the flexure deflects.

A wavelength meter provided by the invention magnifies the optical path length change relative to the deflection of the flexure. A bar is actuated to deflect about a pivot axis defined by a flexural pivot which supports the bar. A retroreflector is mounted on the bar spaced from the pivot axis, which may be associated with one or more fixed retroreflectors. The bar and retroreflectors magnify the optical path length change relative to the flexural displacement of the bar in that the length of an optical path which extends between the retroreflectors and a fixed mirror from which the optical beam is returned changes as the bar is oscillated about the flexural pivot.

The optical path length magnification by means of the bar and retroreflectors, engenders the requirement for accurate wavelength measurement that the same large path length change is produced during the scan for both the input beam and the reference beam. In accordance with the present invention, the beams are caused to traverse identical paths and are separately detected so as to extract wavelength information from the fringes of each beam as they interfere. More particularly, the beams are propagated simultaneously or samples of each beam propagate successively along the same path via the retroreflectors and the fixed mirror and the change in path length as the bar oscillates is identical for the input and for the reference beams. Interference is then directly a function of the wavelength of the beams and errors due to inconsistent path length changes during the scan are eliminated.

Accordingly, it is an object of the present invention to provide an improved Wavemeter® (a trademark of Burleigh Instruments Inc.) laser wavelength meter.

It is a further object of the present invention to provide an improved laser wavelength meter utilizing a flexure instead of linear or rotary bearings.

It is a still further object of the present invention to provide an improved scanning laser wavelength measurement interferometer, in which an input beam and a reference beam are used and the wavelength measurement is based upon the accurately known wavelength of the

reference beam, wherein a large optical path length change sufficient for accuracy in wavelength measurement is obtained where the change in path length accompanies the cycling or oscillation of a flexure.

It is a still further object of the present invention to provide an improved laser interferometer wavelength meter wherein wavelength is measured through the use of separate interference of an input beam and a reference beam wherein the beams traverse the same optical path via a retroreflector which oscillates over an arc and which path is folded at a fixed end mirror.

It is a still further object of the present invention to provide an improved interferometer based wavelength measurement interferometer in which an optical path length change of at least 100mm is obtained via a flexure based mechanism and without the need for rotary or linear bearings.

Briefly described, an interferometer for measurement of the unknown wavelength of an input beam with respect to the known wavelength of a reference beam embodying the invention utilizes a flexural pivot bearing defining a pivot axis for an oscillating bar, and the bar has a retroreflector spaced from the axis. The bar is oscillated with respect to a fixed mirror having a reflecting surface spaced from the bar, which surface is parallel to the bar when the bar is in a position intermediate at the ends of its range of oscillation. Optics associated with the fixed mirror and the retroreflector, which oscillates about the axis, defines a common path of propagation simultaneously or successively, for the input and reference beams. The beams traverse a path via the retroreflector which is folded at the fixed mirror. The optical path executes repeatedly changes in the optical path length as the oscillatory bar pivots about the flexure pivot axis. Measurements are made based upon the interference of part of the input beam after traversing the path with another part of the input beam after it traverses another path. These paths may change length in opposite senses. The other path is provided with an oscillating bar having two sides, separate retroreflectors carried on both sides of the oscillating bar, which may be balanced about the flexural pivot axis. The input beam and reference beam may be split and travel over two identical paths (constituting the arms of the interferometer) which vary in length

in opposite senses as the bar oscillates. The input and reference beams both travel along both of the paths and are combined into an output beam where interference occurs for both beams separately and fringe measurements are carried out to determine the wavelength of the input beam with respect to the wavelength of the reference beam.

The foregoing and other objects, features and advantages of the invention, as well as presently preferred embodiments thereof, will become more apparent from a reading of the following description in connection with the accompanying drawings wherein:

Fig. 1 is a schematic diagram of a laser wavelength measuring, scanning interferometer for measuring the wavelength of an input beam with respect to a reference beam, wherein scanning is supported by a flexural pivot bearing;

Fig. 2A and 2B are plan views of the fixed and movable retroreflectors, the views being taken along the lines 2-2 in Fig. 1 showing paths of the light beams as they traverse the fixed and oscillatory retroreflectors;

Fig. 3 is a schematic diagram illustrating a system for multiplexing the reference and input beams so that samples thereof are transmitted successively along the same path in the interferometer shown in Fig. 1 and also for synchronously detecting the samples to derive output interference signals from the interfering input and reference beams for making wavelength measurements;

Fig. 4 are waveforms illustrating synchronous detection of the reference and input beams, when they are multiplexed and propagate successively in the interferometer of Fig. 1, and also the fringe signals resulting from the interference of the reference beam and the input beam, respectively;

Fig. 5 is a schematic diagram illustrating optics separating the input and reference beams having different wavelengths at the output end of the interferometer of Fig. 1, using a filter beamsplitter;

Fig. 6 is a schematic diagram similar to Fig. 5, showing optical separation of orthogonally polarized input and reference beams at the output end of the interferometer of Fig. 1, using a polarization beamsplitter;

Fig. 7 is a schematic diagram of optics for combining the input and reference beam to travel along identical paths in the interferometer of Fig. 1, which optics may be used alternatively to the beam combining optics shown in Fig. 1;

Fig. 8 is a view of a scanning laser interferometer wavelength meter, in accordance with another embodiment of the invention; and

Fig. 9 is a fragmentary view illustrating a retroreflector array including the oscillatory retroreflector and a pair of fixed retroreflectors at one end of the oscillating bar for further magnifying optical path length change in the interferometer of Fig. 1 or Fig. 8, another similar retroreflector array being located at the other end of its oscillating bar.

Referring to Fig. 1, there is shown a Michelson interferometer based laser wavelength meter 10 that can achieve greater than 100mm in optical path length change, without the use of rolling or sliding bearing scanners. The paths are in the arms 12 and 14 of the interferometer, and the lengths of the path in arm 12 changes in a sense opposite to the path length change in arm 14. Motion during the scan is achieved using a flexural pivot bearing 16 which mounts an oscillating bar 18. This bar 18 may be in the form of a plate having retroreflectors 20 and 22 carried near the ends thereof. The retroreflectors have their centers, or center axis through the apex of the retroreflectors 20 and 22 spaced at equal distances (d) from the pivot axis of oscillation of the bar 18. One of the retroreflectors 20, is in the arm 12 of the interferometer. The other retroreflector 22 is in the other arm 14.

For long life, the flexure 16 operates within its bending limits. According to manufacturer's specifications, such flexures then have extremely long life which the manufacturer's specification indicates is infinite cycle life; thus the flexures can reliably support an infinite number of oscillation cycles reliably, without failing. The flexure is preferably a flexural pivot bearing of the type described in Troeger, U.S. Patent 3,807,029, issued April 30, 1974. This bearing is commercially available from Lucas Aerospace Power Transmission Corporation of Utica, New York and is called their Pre-Flex Flexural Pivot.

The oscillating bar is balanced about the pivot axis defined by the flexure 16. The oscillations are maintained by electromagnetic actuators 24 and 26 made up of coils which are

magnetically coupled to permanent magnets carried near the ends of the oscillating bar 18. Thus the bar 18 is supported in balanced condition by the springs in the flexure 16 without having any need to make contact with the actuating mechanism 24 and 26.

The arms are terminated by a fixed end mirror reflector 28 which has its reflecting surface parallel to the oscillating bar 18 and perpendicular to the center axis of the retroreflectors 20 and 22, when the oscillating bar 18 is in its quiescent condition, which is at the center of its angular range of oscillation. The fixed end mirror is preferably provided by a reflecting surface on a plate, which facilitates alignment of the reflecting surface with respect to the oscillating beam. However, separate fixed end mirrors may be used. The fixed end mirror 28 is a mirror which defines the ends of the arms 12 and 14 and folds the optical beams that traverse the optical paths constituting the arms 12 and 14.

The retroreflectors 20 and 22 are opposed to fixed retroreflectors 30 and 32, which are smaller in cross section radially across their central axis to the apexes thereof than the retroreflectors 20 and 22. The retroreflectors 20, 22, 30, and 32 may be corner cube reflectors. These corner cube reflectors are preferred for ease of alignment. The interferometer provided by the invention is operative without the smaller reflectors. The interferometer, embodying the invention, having only two retroreflectors which are carried on the balanced oscillating bar 18 is described in detail in connection with Fig. 8 hereinafter.

Two possible alignments of the small retroreflector with respect to the larger retroreflector are illustrated in Fig. 2A and 2B. This alignment is shown for the retroreflectors 22 and 32 in arm 14 on the left side of the flexure 16. The other arm 12 has the retroreflectors 20 and 30 in mirror image relationship to the retroreflectors 22 and 32. In Fig. 2A the input beam to the large retroreflector 22 is on the axis joining the diametrical center 36 of the large retroreflector 22 and the diametrical center of the small retroreflector 32, resulting in an output beam positioned on the same axis. In Fig. 2B the input beam to the large retroreflector 22 is displaced from the axis joining the diametrical center 36 of the large retroreflector 22 and the diametrical center of the small retroreflector 32, resulting in an output beam displaced by an equal amount on the opposite side of the axis. Fig. 2B is the preferred alignment for best

separation of the input and output beams. When used as a laser wavelength meter, two beams, namely an input beam of unknown wavelength and a reference beam of accurately known wavelength enter the arms 12 and 14 at a beamsplitter 38. It will be appreciated, of course, that the interferometer may be used for interferometric measurements on a single beam and other than as a laser wavelength meter. When the input and reference beams are used, they must pass through the arms along the same optical path and in coincidence with the path and with each other.

Fig. 1 illustrates the use of an optical multiplexer 40 which may be implemented by a mechanical chopper or shutter 42 as shown in Fig. 3 or an electro-optic shutter which changes the intensity or changes the polarization of the reference beam with respect to the polarization of the input beam. When multiplexed, the input beam and reference beam are launched toward the beamsplitter 38 and introduced into the arms 12 and 14 coincident with each other and along the optical path in these arms as successive samples of the beams.

Interferometric measurements are made by a system utilizing an output detector 44 which may be a photoelectric detector which translates the optical signals, after recombination at the beamsplitter 38 and interference in an output path 46, into electrical signals. These signals are sampled or demultiplexed in synchronism, with the multiplexing thereof by the multiplexer 40, to reconstitute the signals. The signals that are detected are fringes resulting from interference of the input beam after traversing the arms 12 and 14 and returning the output 46. Likewise, similar fringes occur at the output 46 from the interference of the reference beam returned from each of the arms 12 and 14. The returned reference beams, like the returned input beams, are combined and interfere in the output path 46 and are detected by the detector 44. The interference fringes from the reference beam result in the electrical reference signal and are shown in the upper most waveform of Fig. 4. The interference fringes from the input beam result in the electrical signal shown in the lower most waveform of Fig. 4. The successive samples at the output of the multiplexer 40, for example, the chopper 42, occur on opposite phases of the cycle of rotation of the chopper as shown in the center waveform in Fig. 4. These samples are recovered and define the fringes. The periodicity of the fringes is a function of the wavelength of the interfering

beams.

The multiplexing may be carried out by a sampler 48 which is synchronized by the same sync signal as the multiplexer 40. In the case of the use of a chopper 42 as shown in Fig. 3, a motor 50 which rotates the chopper has an encoder 52 on the shaft thereof which is connected to a semicircular disk which provides the chopper 42. This encoder provides the sync signal which is applied to the synchronous sampler 48 which provides the samples of the fringes due to the interference of the reference beam at the output and the fringes due to the interference of the input beam at the output. These samples are respectively transmitted over separate lines 54 to a fringe detector 56 which is coupled to a wavelength measurement unit 58. The wavelength measurement unit may be constituted of logic elements as described in the above referenced Gornall patent or by sampling the input beam laser fringe signal once in each cycle of the reference laser fringe signal and taking the fast Fourier transform (FFT) of the sampled data. A computer program which handles the data may then provide an output which, like the hard logic used in the Gornall patent, is a measurement of the wavelength of the input beam with respect to the reference beam wavelength. The fast Fourier transform approach is described in U.S. Patent 4,654,530, issued to Dybwad on March 31, 1987.

The use of optical multiplexing of the input and reference beams is preferred when the beams are relatively close in wavelength, say within 250 nanometers (nm). When the beams are relatively far apart in wavelength, for example, when the input beam is at a wavelength in the infrared and the reference beam is in the visible (say from a He-Ne laser), the beams may be transmitted simultaneously and traverse the optical paths in the arms 12 and 14. The interfering returned reference beam and the interfering returned input beam may then be separated by a filter beamsplitter 58 and directed to two detectors 60 and 62 for the reference and input beams, respectively. (See Fig. 5).

As shown in Fig. 6, the input and reference beams may be transmitted coincidentally and simultaneously along the optical paths in the arms 12 and 14 as orthogonally polarized (as shown by the dot and arrows 64 and 66). A polarization sensitive beamsplitter 68 separates the beams, which interfere, in the output section 46.

As shown in Fig. 1, the input and reference beam after optical multiplexing are combined by a coupler provided by a beamsplitter 70. A fiber optic coupler 72 may be used as shown in Fig. 7. The input and reference beams travel through fibers 74 and 76 which are coupled at a junction 78 to a third fiber 80, the light launched from the end of the third fiber is collimated by a lens 82 into co-aligned input and reference beams which are directed to the beamsplitter 38. An optical multiplexer, such as a chopper, may be inserted between segments of the input beam fiber 74 and the reference beam fiber 76 for sampling and transmitting these beams successively into the coupler 72. The multiplexer may be a chopper type shutter as shown in Fig. 3.

Returning to Fig. 1, it will be seen that the beams enter the interferometer from the top left and are split into two paths, constituting the arms 12 and 14, by the beamsplitter 38. In each path the beam reflects in succession off the fixed mirrors 80 and 82 disposed to define the path in the arms 12 and 14, respectively. After reflecting from the fixed mirrors 80 and 82, the beams reflect, in succession, off the larger retroreflectors 20 and 22, the smaller retroreflectors 30 and 32 and once more off the larger retroreflectors 20 and 22. Then the beam in each arm is incident on the fixed end mirror 28. This mirror 28 directs the beam returned from either path back through the same set of optical components in that path through the beamsplitter 38. The fringes are created in output path 46 by interference between the input beam as returned from the arm 12 and from the arm 14, and also between the reference beam as returned from the arm 12 and from the arm 14.

The beams entering and exiting the retroreflectors do not need to be in the same plane as shown in Fig. 2A. Rather the retroreflectors have the property that the reflected beam exits precisely parallel to the beam incident on the surface of the retroreflector, but displaced diametrically across the center 36 of the retroreflector. Figs. 2A and 2B show two alignments, one when the input or incident beam and the output or reflected beam from the retroreflectors as shown by the circles with crosses and dots in Figs. 2A and 2B, are in the same plane or across different diameters of the small and large retroreflectors, respectively. The alignment of the retroreflectors is selected in order to minimize cross talk between the incident input and output beams in the retroreflectors.

The large optical path length change obtained from the flexure supported interferometer by virtue of the oscillating bar and the retroreflectors in the two arms 12 and 14, is obtained notwithstanding the limited arc of oscillatory reciprocation, which is within the bending limits of the flexural pivot and is consistent with the long life of the flexure. This arc may be through ±5 degrees. For example, in Fig.1 the change in optical path length between arms 12 and 14 is Δ OPL = 16 d sin Θ. As noted above, d is the distance between the flexure and the centers (36 in Fig. 2) of the large retroreflectors. Θ is the angle of oscillation. For d = 40mm and an oscillation arc of ±5 degrees, the optical path length change in Fig.1 is 110mm.

Referring to Fig. 8, like parts are identified by the same reference numerals as used in Fig. 1. The design of the Michelson interferometer 88 shown in Fig. 8 is the same in concept as used in the wavelength meter 10 in Fig.1. The fixed retroreflectors are not used. Then the optical path length change is Δ OPL = 8 d sin Θ. If d equals 40mm, a deflection of ±10 degrees is needed to produce an optical path length change of 110mm. This may be accomplished by selecting a suitable flexural pivot bearing which can deflect over the ±10 degree arc and remain within its bending limit.

The path length change in Fig. 1 may be further increased by utilizing additional fixed retroreflectors on opposite sides of the center axis of the large retroreflector. An arrangement with three retroreflectors, one moving and an additional fixed retroreflector 84 is illustrated in Fig. 9. By adding more retroreflectors in each arm of the interferometer, the relationship between optical path length change and angular motion is magnified to a greater path length change than that shown in the case of the wavelength meter 10 in Fig. 1

A symmetrical design as shown in Figs. 1 and 8, utilizing a balanced bar is preferred since the weight of the oscillatory bar 18 is balanced about the center at the flexural pivot, making the deflection of the bar 18 insensitive to gravity. Non symmetrical designs may be used, for example, where one of the arms has a retroreflector mounted on an oscillatory bar and the other arm has a fixed end mirror reflector, as in a conventional Michelson interferometer.

Other variations and modifications of the herein described interferometer wavelength meter, within the scope of the invention, will undoubtedly become apparent to those skilled in

this art. Accordingly, the foregoing description should be taken as illustrative and not in a limiting sense.

CLAIMS

1. An interferometer wavelength meter for measurement of the unknown wavelength of an input beam with respect to the known wavelength of a reference beam comprising a flexural pivot defining a pivot axis, an oscillating bar pivotally mounted on said pivot and having a retroreflector thereon spaced from said pivot axis, means for effecting oscillatory reciprocal movement of said oscillating bar over an arc within the bending limit of said pivot, said arc defining the range of said movement, a fixed retroreflector having a reflecting surface spaced from said oscillating bar and parallel thereto when said oscillating bar is in a position intermediate to said arc, a fixed end mirror presenting a reflecting surface to the beam passing through the moving and fixed retroreflectors and defining an end of a folded optical path, means for defining a common path of propagation for said input and reference beams along a path containing said moving and fixed retroreflectors and turning upon reflection from said fixed end mirror, which path executes repeated changes in length as said oscillating bar executes said reciprocal oscillatory motion about said axis.

2. The interferometer according to Claim 1 further comprising a beamsplitter dividing each of said input beam and said reference beam along two paths and recombining said return beams to said measurement making means, and means for making said measurement based upon the interference of said returned input beams and said returned reference beams.

3. The interferometer according to Claim 1 wherein said oscillating bar is balanced about said pivot axis and has two sides, each side carrying separate retroreflectors having centers spaced the same distance from said pivot axis, said reflecting surface of said fixed end mirror being opposed to said retroreflectors on said oscillating bar and being perpendicular to said oscillating bar when said bar is in the middle of the range of oscillation thereof.

4. The interferometer according to Claim 3 wherein said fixed retroreflectors define said path and are smaller than said retroreflectors on said oscillating bar and are opposed thereto whereby to increase the magnitude of the change in the length of said optical path over the path

length change without said fixed retroreflector.

5. The interferometer according to Claim 4 wherein said smaller retroreflectors have the centers thereof offset from the center of said larger retroreflectors on said bar, said offset providing spacing of said input and return beams which minimizes cross talk there between.

6. The interferometer according to Claim 1 wherein said common path defining means comprises a beamsplitter for reflecting one of said input and reference beams and transmitting the other onto the same, common path.

7. The interferometer according to Claim 2 further comprising a filter beamsplitter in the path of said return input and reference beams for separating said beams for application to said measurement making means.

8. The interferometer according to Claim 2 wherein said input and reference beams are orthogonally polarized, and means for separating said beams for application to said measurement making means using a polarization sensitive beamsplitter.

9. The interferometer according to Claim 2 wherein said common path defining means comprises means for multiplexing said input and reference beams ahead of said beamsplitter so that said input and reference beams are transmitted in samples thereof successively along said optical path, and said measurement making means comprises sampling means for the demultiplexing said returned input and reference beams for separate processing thereof to detect the interference of each of said reference and input beams.

10. The interferometer according to Claim 1 wherein said common path defining means comprises first and second fiber optics separately carrying said input and reference beams, said fiber optics being coupled together to provide a common fiber launching said beams into said common path.

11. The interferometer according to Claim 10 further comprising means for multiplexing said beams in said fiber optics for launching samples of said beams successively into said common path.

12. A Michelson interferometer having an oscillatory bar, a flexural pivot bearing said bar for oscillation over an angular range of travel within the bending range of said pivot, a

retroreflector carried on said bar, a fixed end mirror presenting a reflecting surface to said retroreflector and defining an end of a folded optical path the length of which is repeatedly changed as said bar oscillates and along which path an optical beam is in interfering relationship for wavelength measurement.

13. The interferometer according to Claim 12 wherein said reflecting surface is parallel to said oscillatory bar at an intermediate position of said oscillatory bar within said angular range of oscillation.

14. The interferometer according to Claim 12 further comprising a detector responsive to interference of said beam, a beamsplitter along said path between said fixed end mirror and said detector.

15. The interferometer according to Claim 12 wherein said oscillatory bar has ends on opposite sides of a pivot axis defined by said flexural pivot, said retroreflector being one of a pair of retroreflectors spaced from each other equal distances from said axis.

16. The interferometer according to Claim 15 wherein said oscillating bar and retroreflectors are balanced about said axis.

17. The interferometer according to Claim 12 wherein at least one fixed retroreflector is opposed to said retroreflector on said oscillatory bar, said fixed retroreflector is smaller in width than said retroreflector on said oscillatory bar and has a center offset from a center of said retroreflector on said oscillatory bar, said optical beam incident on said fixed end mirror being an incident beam and said beam returned from said end mirror being a return beam.

18. The interferometer according to Claim 17 wherein said retroreflectors have a central axis, said central axis of said retroreflectors being aligned in offset relationship with said incident and return beams.

19. The interferometer according to Claim 17 wherein a plurality of smaller fixed retroreflectors are disposed with their reflecting surfaces opposing the reflecting surfaces of said retroreflector on said oscillatory bar, and said smaller retroreflectors having central axes offset from the central axis of said retroreflector on said oscillatory beam.

20. The interferometer according to Claim 17 wherein said incident and return beams

are incident on said retroreflectors generally along a single line intersecting a central axis of said retroreflectors.

21. The interferometer, according to Claim 17, wherein said incident and return beams are incident on said retroreflectors along lines which are offset on opposite sides of the line intersecting the central axis of said retroreflectors.

22. The interferometer according to Claim 12 further comprising electromagnetic actuator means in proximity to said oscillatory bar for generating magnetic forces perpendicular to said pivot axis to cause flexural oscillation of said oscillatory bar.

23. The interferometer according to Claim 12 further comprising means for projecting an input beam of unknown wavelength and a reference beam of known wavelength simultaneously or successively in coincident relationship along said optical path which is of the same length and undergoes the same change in length with oscillation of said oscillatory bar, and means responsive to interference in said input beam before and after return from said end mirror and interference between said reference beam before and after return from said end mirror for measuring wavelength of said input beam with respect to said reference beam.

24. The interferometer according to Claim 12 wherein said spacing of said retroreflectors with respect to said flexural pivot and wherein said retroreflectors are sized so as to define a change in optical path of 100mm or more as said oscillatory bar moves over said angular range.

25. An interferometer which measures the wavelength of a beam of unknown wavelength with respect to a reference beam of known wavelength which comprises means for propagating said beams simultaneously or successively in coincident relationship along an optical path which undergoes a change in length, and means responsive to interference in said beams for measuring said wavelength of said input beam with respect to said reference beam.

26. The interferometer according to Claim 25 further comprising an oscillatory bar having at least one retroreflector and a fixed mirror for defining said optical path which undergoes said change in length.

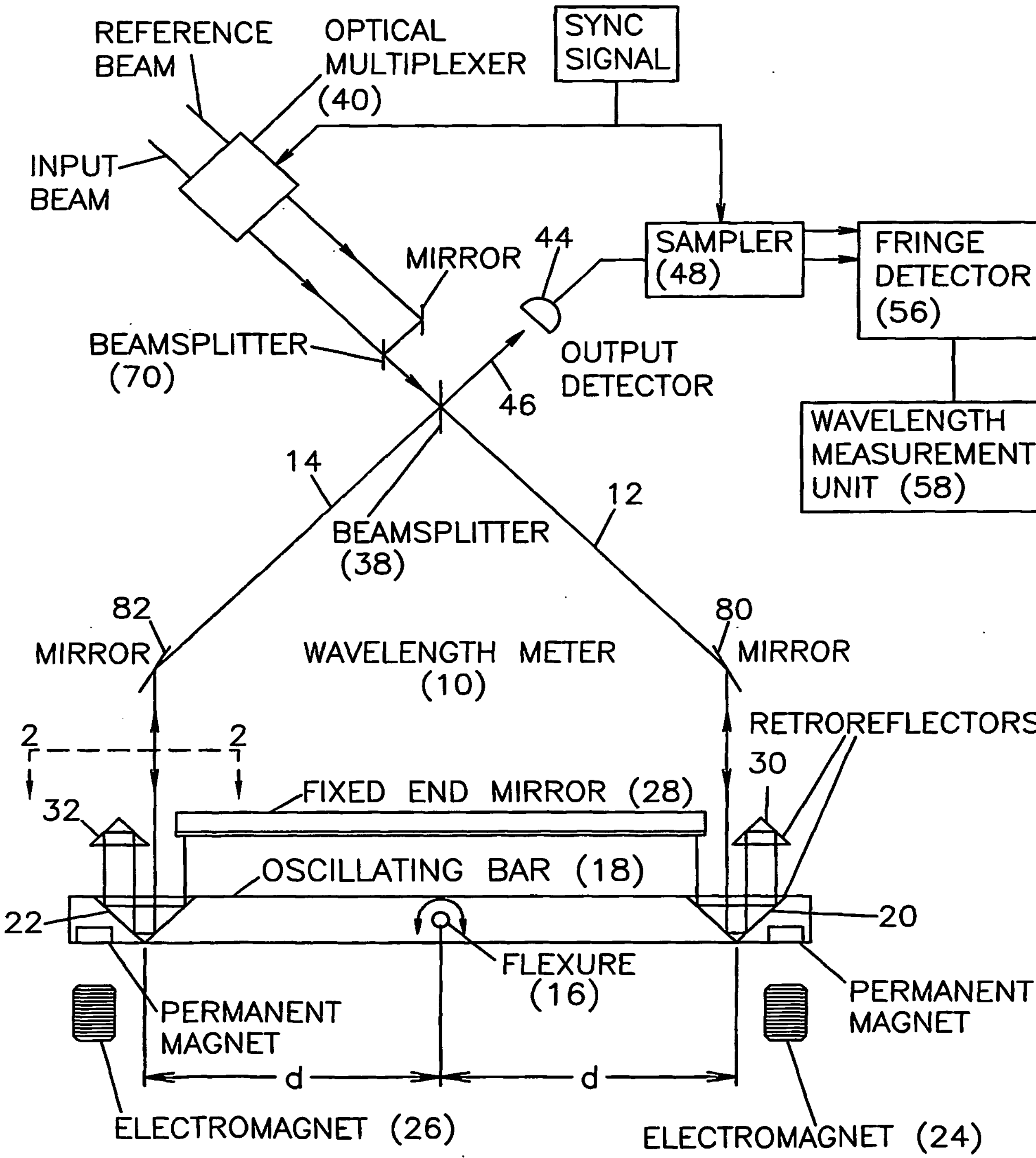
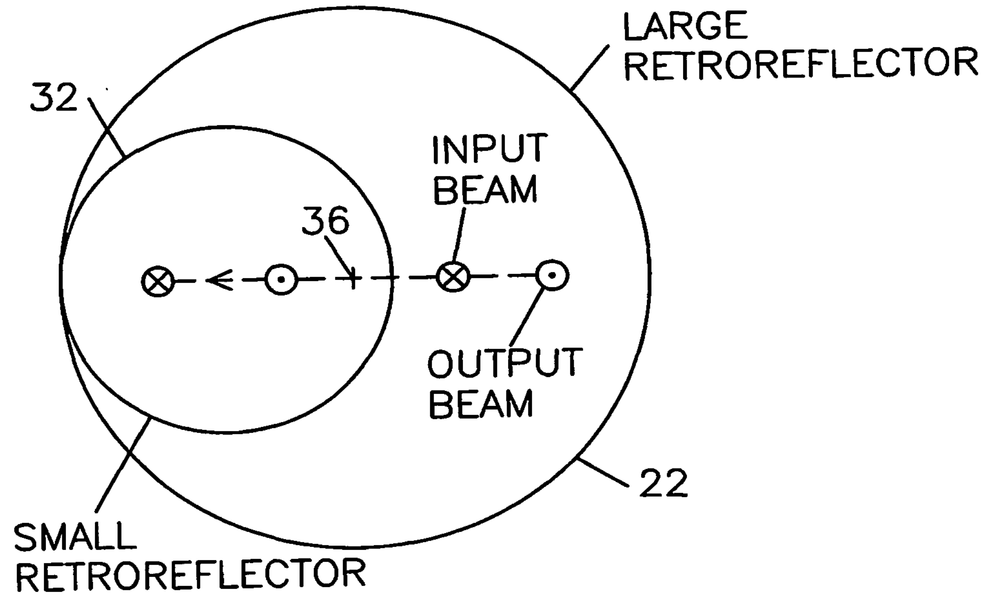

REFERENCE BEAM
OPTICAL MULTIPLEXER (40)
SYNC SIGNAL
INPUT BEAM
MIRROR
44
SAMPLER (48)
FRINGE DETECTOR (56)
BEAMSPLITTER (70)
OUTPUT DETECTOR
46
WAVELENGTH MEASUREMENT UNIT (58)
14
12
BEAMSPLITTER (38)
82
80
MIRROR
WAVELENGTH METER (10)
MIRROR
RETROREFLECTORS
2
2
30
FIXED END MIRROR (28)
32
OSCILLATING BAR (18)
22
20
FLEXURE (16)
PERMANENT MAGNET
PERMANENT MAGNET
d
d
ELECTROMAGNET (26)
ELECTROMAGNET (24)

FIG. 1.


LARGE
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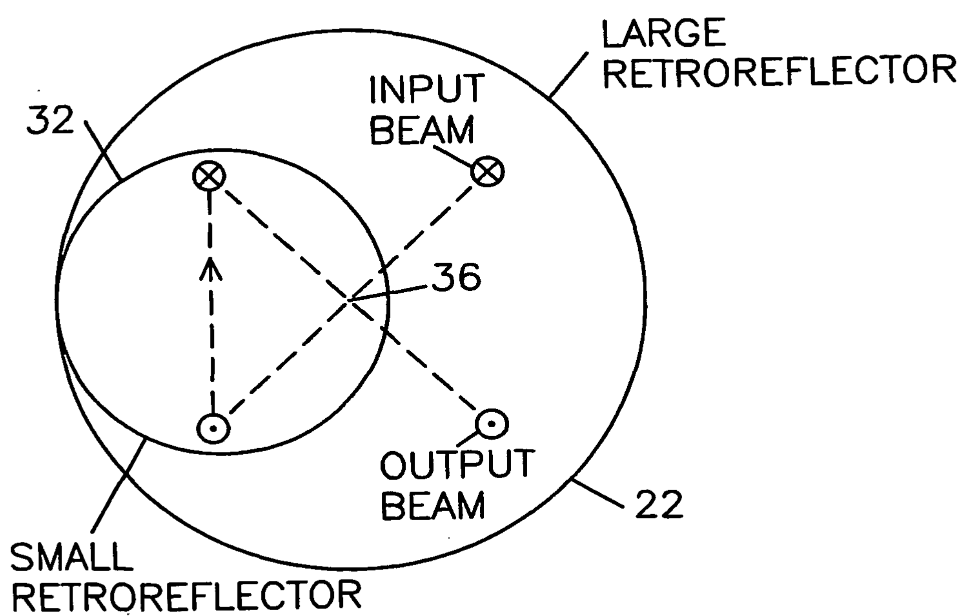
32
INPUT
BEAM
36
OUTPUT
BEAM
22
SMALL
RETROREFLECTOR

FIG. 2A.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INPUT
BEAM
32
36
OUTPUT
BEAM
22
SMALL
RETROREFLECTOR

FIG. 2B.

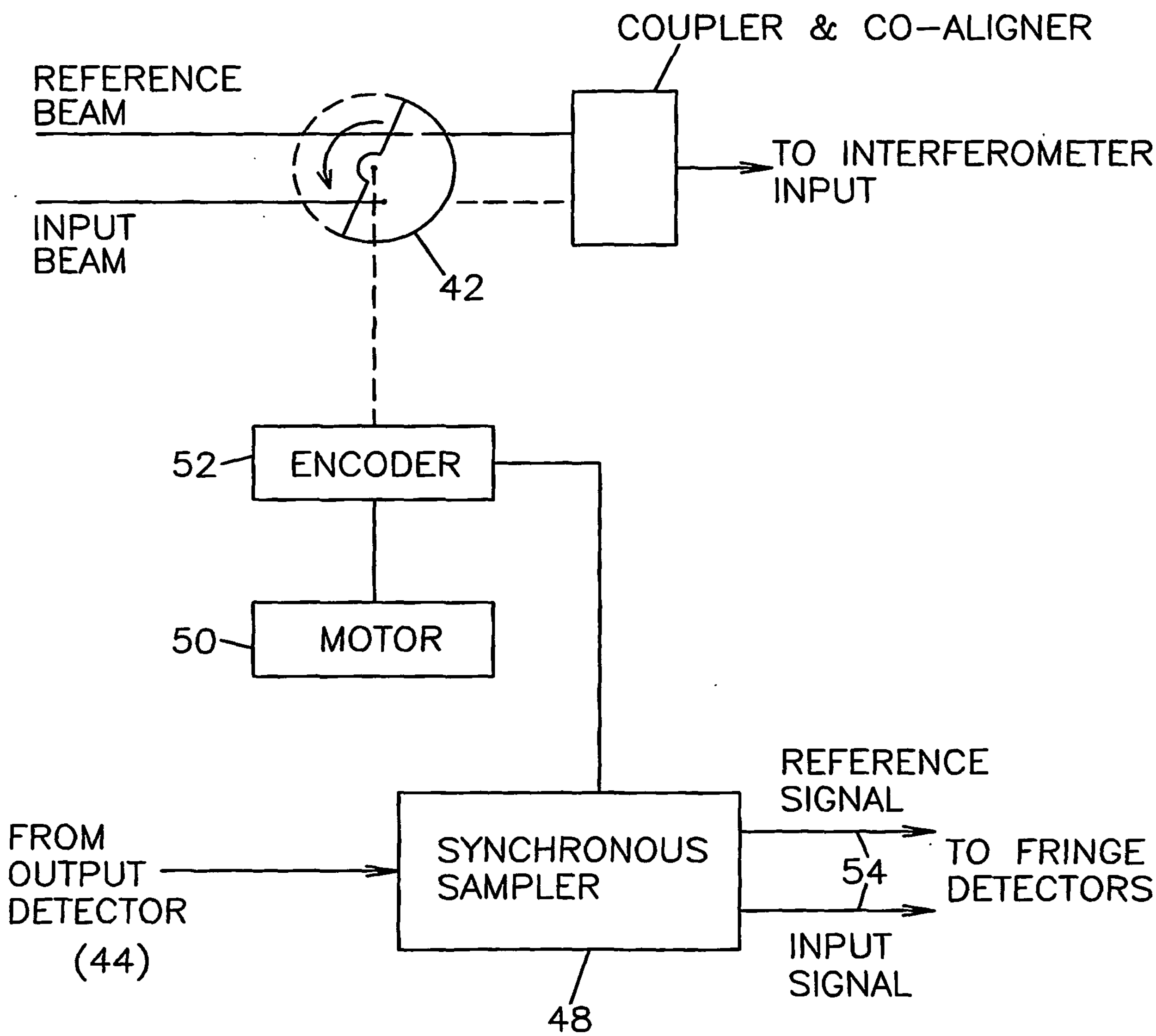
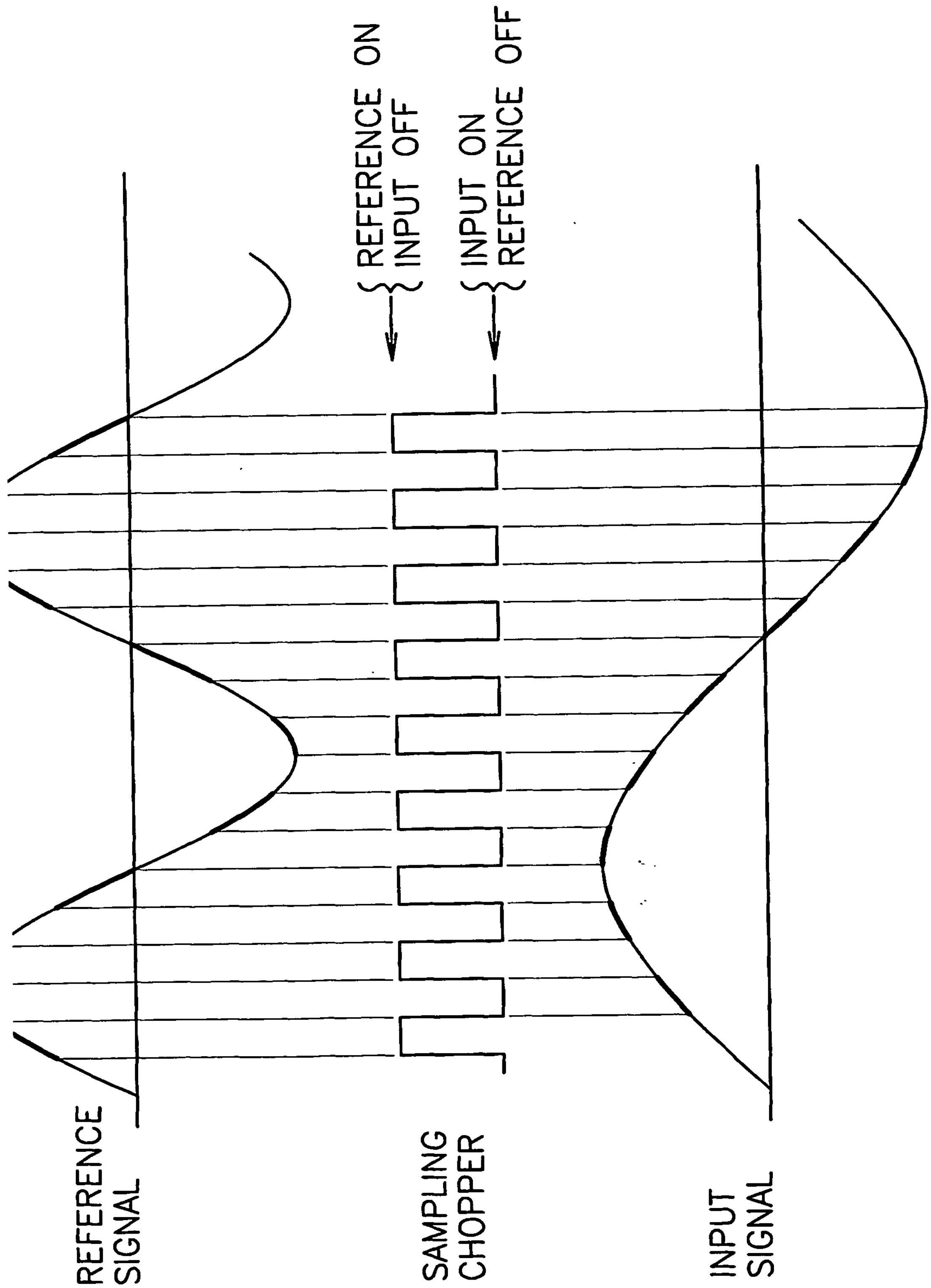

COUPLER & CO-ALIGNER
REFERENCE BEAM
TO INTERFEROMETER INPUT
INPUT BEAM
42
52
ENCODER
50
MOTOR
REFERENCE SIGNAL
FROM OUTPUT DETECTOR (44)
SYNCHRONOUS SAMPLER
54
TO FRINGE DETECTORS
INPUT SIGNAL
48

FIG. 3.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SAMPLING CHOPPER
INPUT SIGNAL
REFERENCE ON
INPUT OFF
INPUT ON
REFERENCE OFF

FIG. 4.

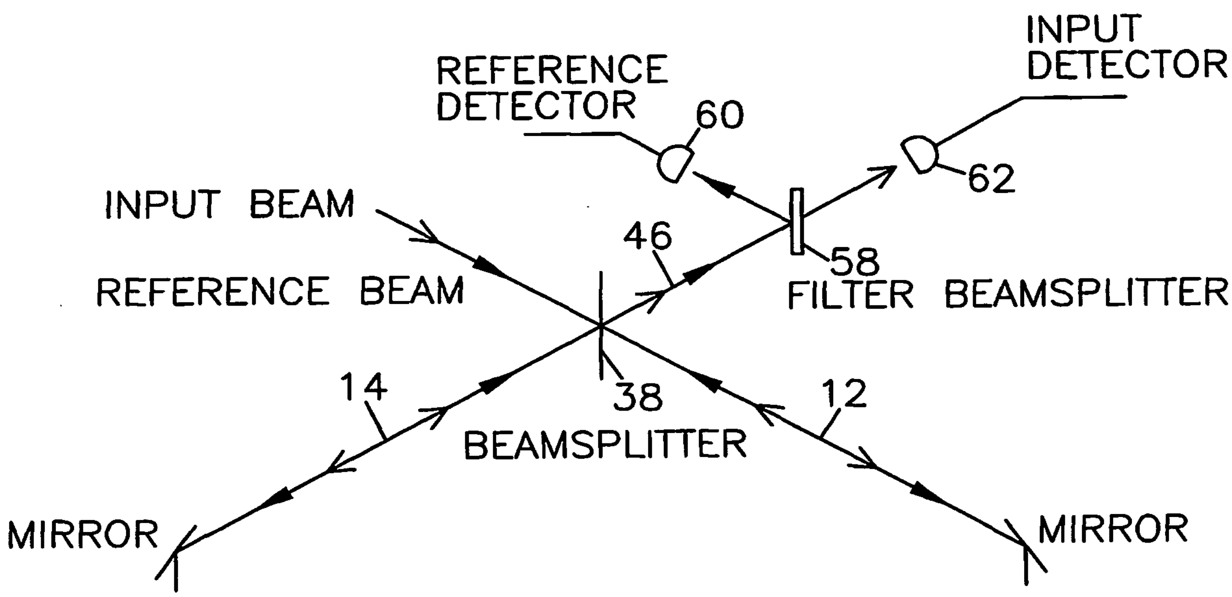
INPUT
DETECTOR
REFERENCE
DETECTOR
60
62
INPUT BEAM
46
58
REFERENCE BEAM
FILTER BEAMSPLITTER
14
38
12
BEAMSPLITTER
MIRROR
MIRROR

FIG. 5.

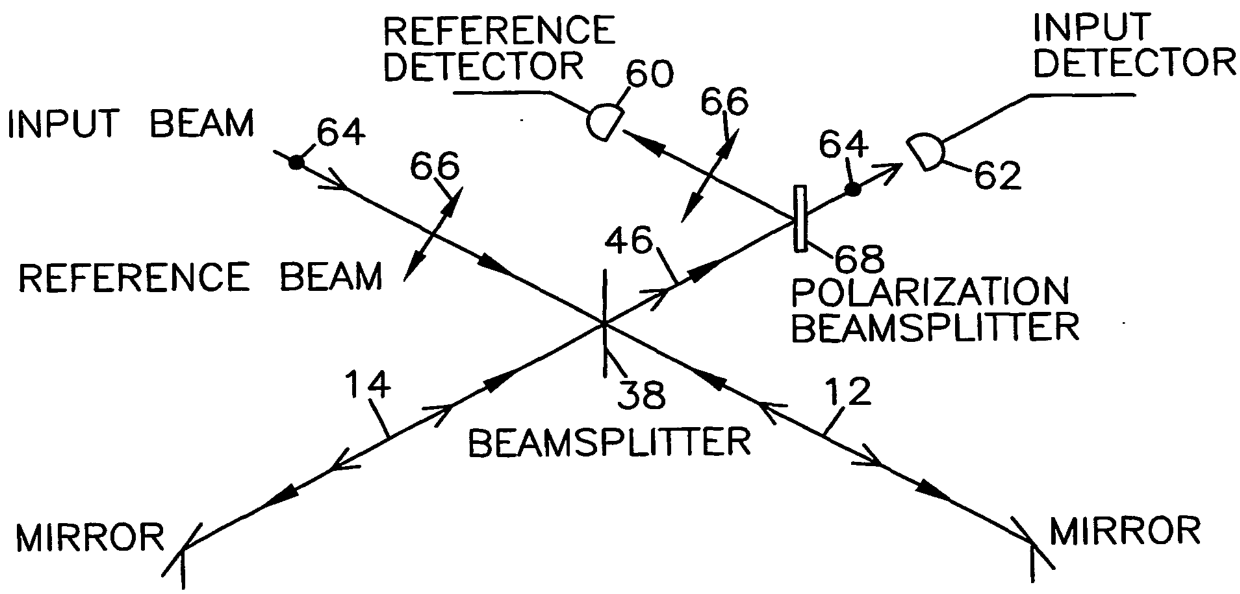
REFERENCE
DETECTOR
60
INPUT
DETECTOR
INPUT BEAM
64
66
66
64
62
REFERENCE BEAM
46
68
POLARIZATION
BEAMSPLITTER
14
38
12
BEAMSPLITTER
MIRROR
MIRROR

FIG. 6.

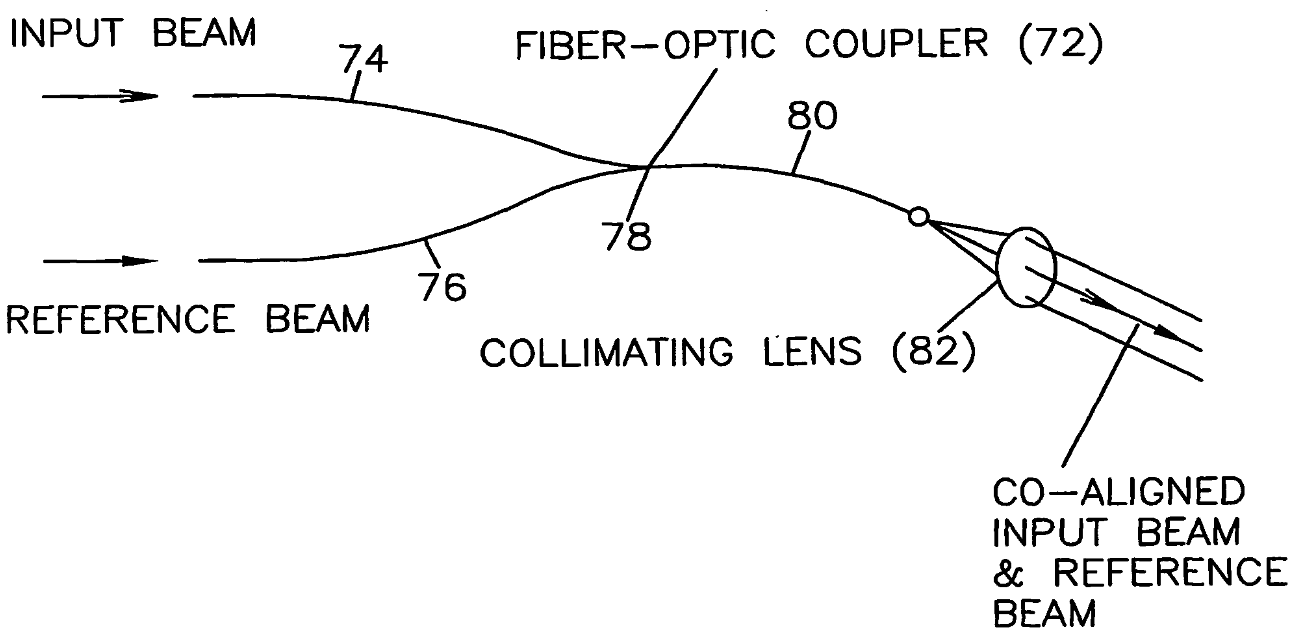
INPUT BEAM
74
FIBER-OPTIC COUPLER (72)
80
78
76
REFERENCE BEAM
COLLIMATING LENS (82)
CO-ALIGNED
INPUT BEAM
& REFERENCE
BEAM

FIG. 7.

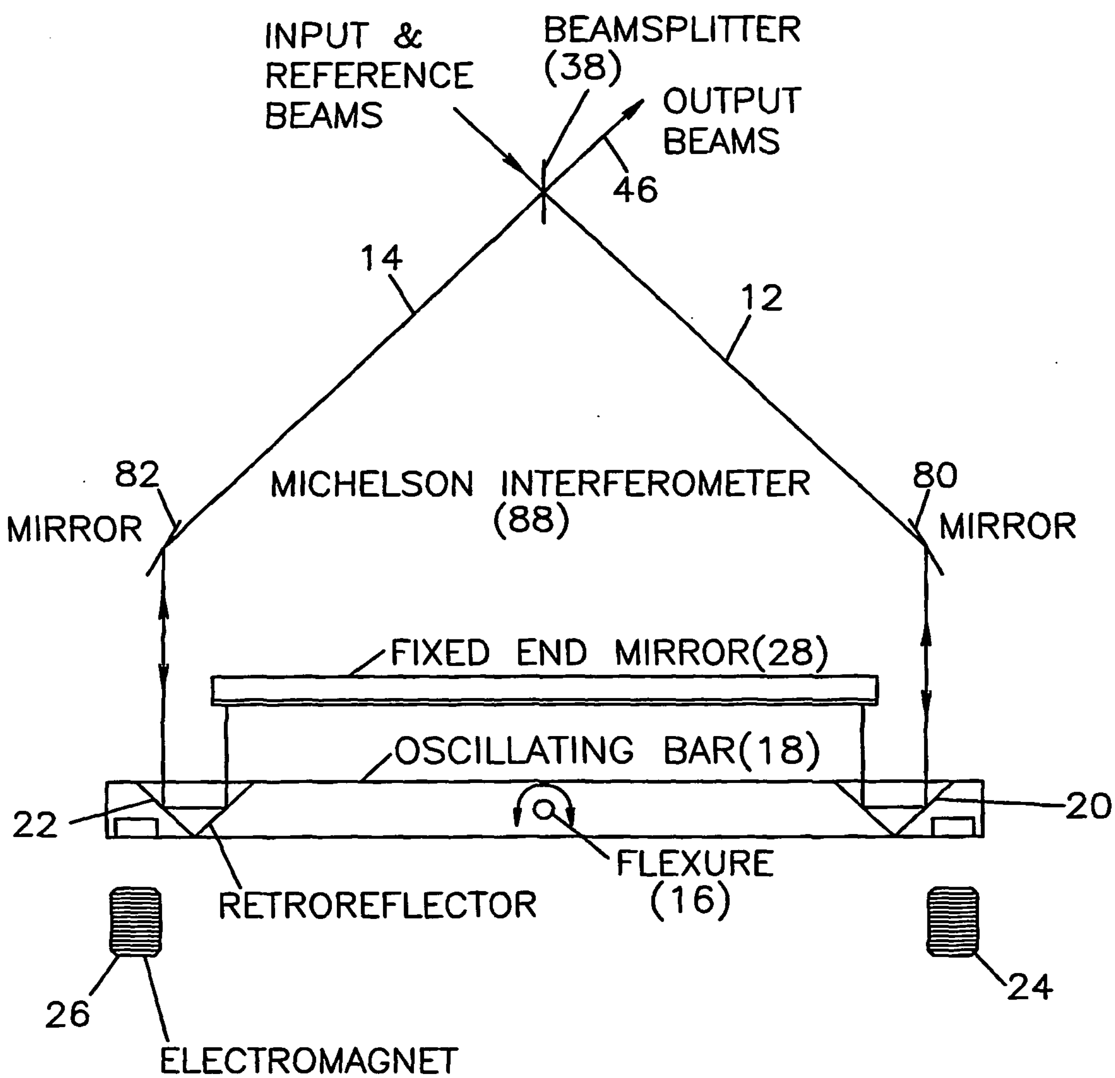
INPUT &
REFERENCE
BEAMS
BEAMSPLITTER
(38)
OUTPUT
BEAMS
46
14
12
82
MIRROR
MICHELSON INTERFEROMETER
(88)
80
MIRROR
FIXED END MIRROR(28)
OSCILLATING BAR(18)
22
20
RETROREFLECTOR
FLEXURE
(16)
26
24
ELECTROMAGNET

FIG. 8.

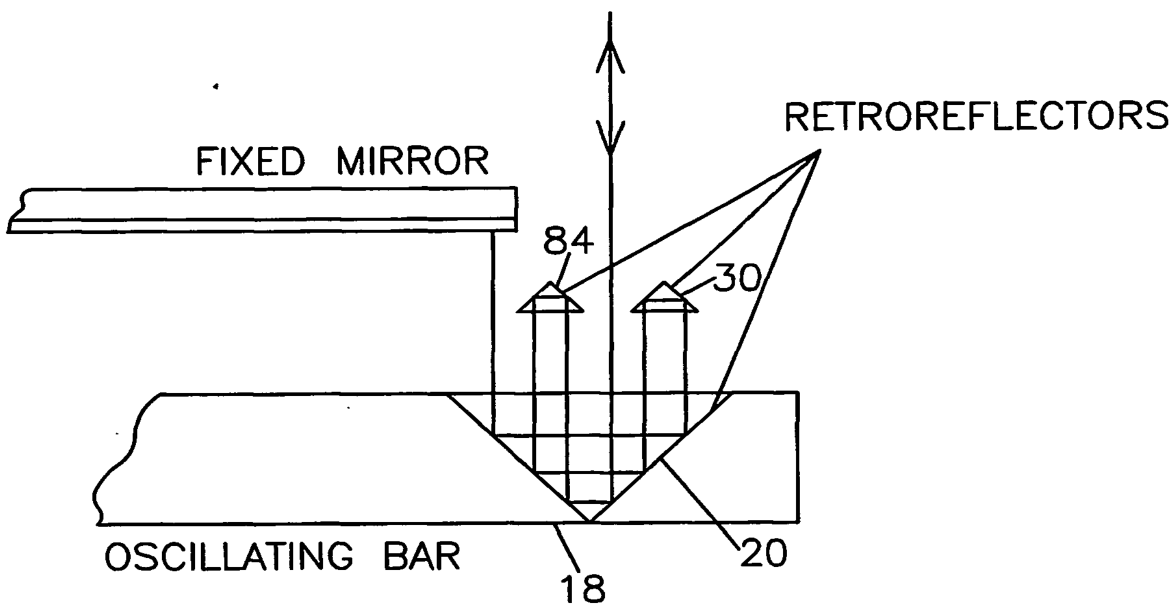

FIG. 9.